

SPITZER IRS OBSERVATIONS OF DISKS AROUND BROWN DWARFS IN THE TW HYDRA ASSOCIATION¹

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ABSTRACT

Using SpeX at the NASA Infrared Telescope Facility and the *Spitzer* Infrared Spectrograph, we have obtained infrared spectra from 0.7 to 30 μm for three young brown dwarfs in the TW Hydra Association ($\tau \sim 10$ Myr), 2MASSW J1207334-393254, 2MASSW J1139511-315921, and SSSPM J1102-3431. The spectral energy distribution for 2MASSW J1139511-315921 is consistent with a stellar photosphere for the entire wavelength range of our data while the other two objects exhibit significant excess emission at $\lambda > 5 \mu\text{m}$. We are able to reproduce the excess emission from each brown dwarf using our models of irradiated accretion disks. According to our model fits, both disks have experienced a high degree of dust settling. We also find that silicate emission at 10 and 20 μm is absent from the spectra of these disks, indicating that grains in the upper disk layers have grown to sizes larger than $\sim 5 \mu\text{m}$. Both of these characteristics are consistent with previous observations of decreasing silicate emission with lower stellar masses and older ages. These trends suggest that either 1) the growth of dust grains, and perhaps planetesimal formation, occurs faster in disks around brown dwarfs than in disks around stars, or 2) the radii of the mid-IR-emitting regions of disks are smaller for brown dwarfs than for stars, and grains grow faster at smaller disk radii. Finally, we note the possible detection of an unexplained emission feature near 14 μm in the spectra of both of the disk-bearing brown dwarfs.

Subject headings: accretion disks – planetary systems: protoplanetary disks – stars: formation — stars: low-mass, brown dwarfs — stars: pre-main sequence

1. INTRODUCTION

One of the first steps toward the formation of planets is the growth and settling of dust grains in a circumstellar accretion disk (Weidenschilling & Cuzzi 1993). A common diagnostic of grain evolution in disks is the silicate emission near 10 μm (Natta et al. 2000). Measurements of this feature have been performed for young stars ($\tau \sim 1$ Myr) across a wide range of spectral types, from early B to late M (Furlan et al. 2005; Kessler-Silacci et al. 2006; Sicilia-Aguilar et al. 2007). In these data, silicate emission becomes weaker at later spectral types, which could be explained by more advanced grain evolution or sedimentation in disks around low-mass objects or a luminosity dependence of the radius in the disk at which silicate emission is produced (Kessler-Silacci et al. 2007; Sicilia-Aguilar et al. 2007).

Recent studies also have begun to explore the evolution of silicate emission with time for low-mass sys-

tems. Observations with the *Spitzer Space Telescope* have found that disks around low-mass stars and brown dwarfs exhibit weaker silicate emission in Upper Scorpius ($\tau \sim 5$ Myr, Scholz et al. 2007) than in Chamaeleon I ($\tau \sim 3$ Myr, Apai et al. 2005) and Taurus ($\tau \sim 1$ Myr, Furlan et al. 2005), which is consistent with the growth of grains to larger sizes, the settling of dust to midplane, or both, as time goes on. However, according to a recent study, this correlation between silicate emission and age does not apply to the brown dwarf 2MASSW J1207334-393254 (henceforth 2M 1207-3932, Gizis 2002) in the TW Hya Association (TWA, $\tau \sim 10$ Myr, Mamajek 2005; Barrado y Navascués et al. 2006). Riaz & Gizis (2007) constructed a mid-infrared (IR) spectral energy distribution (SED) for this object using broad-band photometry from Sterzik et al. (2004) and Riaz et al. (2006), which seemed to indicate the presence of silicate emission. As a result, they concluded that the disk around 2M 1207-3932 has experienced little dust processing relative to stars at the same age.

To investigate the evolution of silicate emission in brown dwarf disks more definitively, we have performed mid-IR spectroscopy on 2M 1207-3932 and two other brown dwarfs in TWA with the *Spitzer* Infrared Spectrograph (IRS; Houck et al. 2004). In this Letter, we describe these observations and supporting near-IR spectroscopy (§ 2), examine these data for silicate and continuum emission from circumstellar dust (§ 3.1), and fit these data with the predictions of disk models (§ 3.2).

2. OBSERVATIONS

2.1. Near-infrared Spectroscopy

We obtained low-resolution near-IR spectra of 2M 1207-3932 and two other brown dwarfs in TWA, 2MASSW J1139511-315921 (2M 1139-3159, Gizis 2002)

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and SSSPM J1102-3431 (SS 1102-3431, Scholz et al. 2005a), with SpeX (Rayner et al. 2003) at the NASA Infrared Telescope Facility (IRTF) on the night of 2005 December 14. These data were reduced with the Spextool package (Cushing et al. 2004) and corrected for telluric absorption (Vacca et al. 2003). The final spectra extend from 0.8-2.5 μm and exhibit a resolving power of $R = 100$. We flux calibrated the spectra using photometry at J , H , and K_s from the Point Source Catalog of the Two-Micron All-Sky Survey (2MASS, Skrutskie et al. 2006). To measure spectral types from these data, we compared them to SpeX data for young objects that have been classified at optical wavelengths. The strengths of the TiO, VO, and H₂O absorption bands indicate a spectral type of M8.5 for each object, which is consistent with the optical types of M8-M8.5 reported by Gizis (2002) and Scholz et al. (2005a). The spectra of 2M 1139-3159 and SS 1102-3431 are slightly redder than the spectrum of 2M 1207-3932 in a manner that is consistent with reddening by interstellar dust. Therefore, we dereddened the spectra of 2M 1139-3159 and SS 1102-3431 by $A_V = 0.8$ and $A_V = 0.5$, respectively, to match the data for 2M 1207-3932.

2.2. Mid-infrared Spectroscopy

We obtained low-resolution mid-IR spectra of 2M 1139-3159, 2M 1207-3932, and SS 1102-343 on 3 July 2005, 29 July 2006, and 3 July 2005, respectively, with IRS aboard *Spitzer* as a part of the Guaranteed Time Observations of the IRS instrument team. We used both low-resolution IRS modules, Short-Low and Long-Low, which cover 5.3-14 and 14-40 μm , respectively, with a resolution of $\lambda/\Delta\lambda \sim 90$. The total exposure time for each target was ~ 4000 sec. The spectra were extracted and calibrated from the basic calibrated data using the standard SMART data analysis package for IRS (Higdon et al. 2004). The spectra were reduced with the methods that have been previously applied to IRS data for low-mass members of Taurus (Furlan et al. 2005).

3. ANALYSIS

3.1. Disk Emission

In Figure 1, we plot the SED of 2M 1139-3159 from 0.7 to 24 μm using photometry from 2MASS and *Spitzer* (Riaz et al. 2006) and the spectra that we obtained with SpeX and IRS. For comparison, we include the SED of a field dwarf with a similar spectral type (VB 10, M8V) after scaling it to match 2M 1139-3159 at J , H , and K_s . 2M 1139-3159 is slightly brighter than the field dwarf beyond 3 μm , but this is probably a reflection of a small difference in the photospheric near- to mid-IR colors between pre-main-sequence objects and field dwarfs rather than excess emission from dust given that the mid-IR slopes are the same for the two objects. Therefore, we believe that the SED of 2M 1139-3159 represents a good estimate of the SEDs of the stellar photospheres of the other two brown dwarfs, 2M 1207-3932 and SS 1102-3431. We compare the SpeX and IRS spectra of these three objects in Figure 2. Relative to the photospheric SED of 2M 1139-3159, the SEDs of 2M 1207-3932 and SS 1102-3431 exhibit significant excess emission longward of 5 μm . These results for 2M 1207-3932 and 2M 1139-3159 are consistent with those of previous studies, which have found evidence of a disk for

2M 1207-3932 but not for 2M 1139-3159 based on *Spitzer* photometry (Riaz et al. 2006), ground-based photometry (Jayawardhana et al. 2003; Sterzik et al. 2004), and H α emission (Mohanty et al. 2003, 2005). For SS 1102-3431, the only previous constraint on the presence of a disk is the H α spectroscopy by Scholz et al. (2005b), who concluded that accretion is occurring at a very low level, if at all. Thus, our IRS observations provide the first definitive detection of a disk around this object.

In addition to detecting the presence of excess emission, previous mid-IR photometric measurements of 2M 1207-3932 have been used to constrain the strength of the silicate emission feature at 10 μm . Based on ground-based photometry at 8.7 and 10.4 μm , Sterzik et al. (2004) found that 2M 1207-3932 did not exhibit strong silicate emission. However, 2M 1207-3932 was slightly brighter at 10.4 μm than at 8.7 μm , which was interpreted as evidence of modest silicate emission by Riaz & Gizis (2007). As shown in Figure 2, silicate emission at 10 and 20 μm is absent in the IRS spectrum of 2M 1207-3932. The same is true for the other disk-bearing brown dwarf in our sample, SS 1102-3431. In contrast to these brown dwarf disks, the disks around stars in TWA do produce silicate emission (Uchida et al. 2004; Furlan et al. 2007).

Although silicate emission at 10 and 20 μm is not present in the IRS data for 2M 1207-3932 and SS 1102-3431, it appears that a weak emission feature may be detected near 14 μm in the spectra of both objects. Because of its large width, the feature is probably produced by a mineral rather than a gas. We cannot identify a plausible source of this emission that is consistent with the available data for these disks (e.g., large grain sizes, absence of other emission lines).

3.2. Disk Model

We have modeled the mid-IR excess emission from 2M 1207-3932 and SS 1102-3431 as arising from irradiated accretion disks by following the procedures from D'Alessio et al. (1998, 1999, 2001, 2006). For the stellar photosphere of each object, we have adopted an effective temperature of 2555 K, which is estimated by combining a spectral type of M8.5 (§ 2.1) with the temperature scale from Luhman et al. (2003). A brown dwarf with this temperature at the age of the TW Hya association (10 Myr) is predicted to have a bolometric luminosity of $0.0024 L_\odot$ and a mass of $0.025 M_\odot$ by the evolutionary models by Chabrier et al. (2000). These values of temperature and luminosity correspond to a stellar radius of $0.25 R_\odot$. For the disk calculations, we adopted a uniform accretion rate of $\dot{M} = 10^{-11} M_\odot \text{ yr}^{-1}$ (Scholz et al. 2005b). We include dust settling in the disk following the methods of D'Alessio et al. (2006). In short, two populations of grains co-exist in the disk, both with size distributions given by $n(a) \sim a^{-3.5}$ where a is the grain radius (Mathis, Rumpl, & Nordsieck 1977). The minimum radius for both populations is 0.005 μm ; grains around the midplane have a maximum radius of $a_{\text{max}} = 1 \text{ mm}$, while a_{max} in the upper layers is adjusted to produce the best fit to the SED. In addition, the dust-to-gas mass ratio of the small grains is parameterized in terms of ϵ , which is the ratio normalized by the standard interstellar value of ~ 0.01 . The model includes an inner disk wall illuminated by the central brown dwarf and located at the

dust sublimation radius of $3.3 R_*$. The outer radii of the disks around 2M 1207-3932 and SS 1102-3431 are not constrained by the available data; we adopt a value of $R_{out} = 50$ AU for each disk.

We have calculated SEDs for a range of values of the viscosity parameter (α), ϵ , disk inclination (i), and wall height (z_{wall}) and compared the results to the observed SEDs of 2M 1207-3932 and SS 1102-3431. The SEDs of the best model fits are shown in Figs. 3 and 4. The data for both objects are well-matched by $\alpha = 0.001$, $\epsilon = 0.001$, and $i = 60^\circ$. We are able to reproduce the small difference in the SEDs of the two objects (Figure 2) by using $z_{wall} = 1 H$ for 2M 1207-3932 and $z_{wall} = 2 H$ for SS 1102-3431, where H is the disk scale height, which is 1.15×10^{-4} AU for the adopted sublimation temperature of 1400 K. These differences in z_{wall} may indicate that the inner disks have different degrees of dust settling. We note that other combinations of values for α , ϵ , and i also produce reasonable fits to the observed SEDs. Additional data, such as photometry at longer wavelengths, are needed to further constrain these parameters. However, the relatively blue slopes of the mid-IR SEDs of 2M 1207-3932 and SS 1102-3431 definitely indicate a large degree of dust settling to the disk midplane (i.e., small ϵ in our treatment, Watson et al. 2008).

The absence of silicate emission (Figure 2) indicates that grains have grown significantly in the upper disk layers (cf. D'Alessio et al. 2006). We show in Figure 4 a series of disk models in which we have varied a_{max} in the upper disk layers from $0.25 \mu\text{m}$ (ISM grains) to $100 \mu\text{m}$. As expected, the silicate emission becomes weaker as a_{max} grows. Based on the comparison to our models, the absence of silicate emission in the IRS data for 2M 1207-3932 and SS 1102-3431 indicates that grains in the upper disk layers have grown to sizes of $a_{max} \gtrsim 5 \mu\text{m}$.

4. CONCLUSIONS

We have presented near- and mid-IR spectroscopy for three young brown dwarfs in the TW Hya association. Two of these objects, 2M 1207-3932 and SS 1102-3431, exhibit significant mid-IR emission above that expected from a stellar photosphere. We have successfully reproduced the excess emission from each brown dwarf with an irradiated accretion disk model that includes dust settling. Both disks exhibit high degrees of dust settling to the midplane based on the relatively blue mid-IR slopes of their SEDs. In addition, our IRS spectra reveal an absence of silicate emission at 10 and $20 \mu\text{m}$ in both objects, which indicates that the disks have experienced significant grain growth in their upper layers ($a_{max} \gtrsim 5 \mu\text{m}$). These results for 10-Myr-old brown dwarfs support and extend the previously observed trend of decreasing silicate emission with lower stellar masses and older ages. This trend may indicate that grain growth and planetesimal formation occur more rapidly in disks around brown dwarfs than in disks around stars, or that grains grow faster at smaller disk radii, and it is at smaller radii where mid-IR emission is produced for objects at lower masses (Kessler-Silacci et al. 2007; Sicilia-Aguilar et al. 2007).

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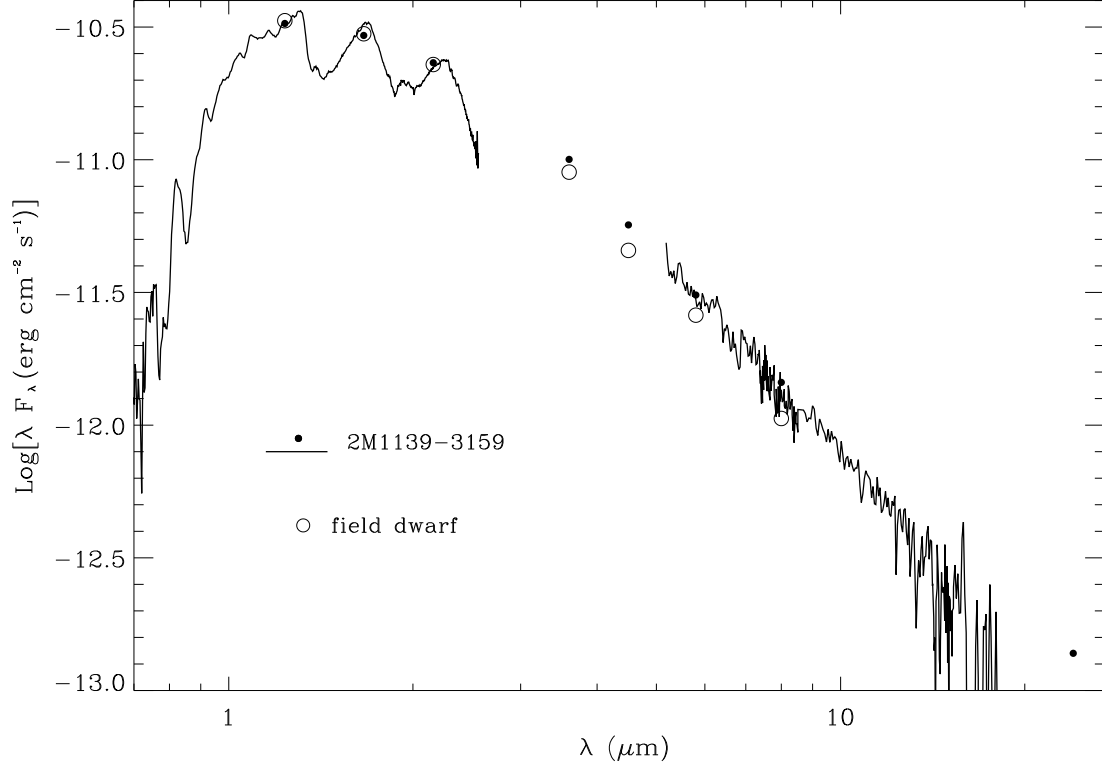


FIG. 1.— SEDs of the young brown dwarf 2M 1139-3159 (*lines and filled circles*) and the field dwarf VB 10 (*open circles*). The SED of 2M 1139-3159 is consistent with that of the field dwarf and does not show excess emission at long wavelengths from a circumstellar disk. The spectra of 2M 1139-3159 were obtained with SpeX and IRS in this work. The photometric measurements are from 2MASS, Patten et al. (2006), and Riaz et al. (2006). The SED for VB 10 has been scaled to match that of 2M 1139-3159 at J , H , and K_s .

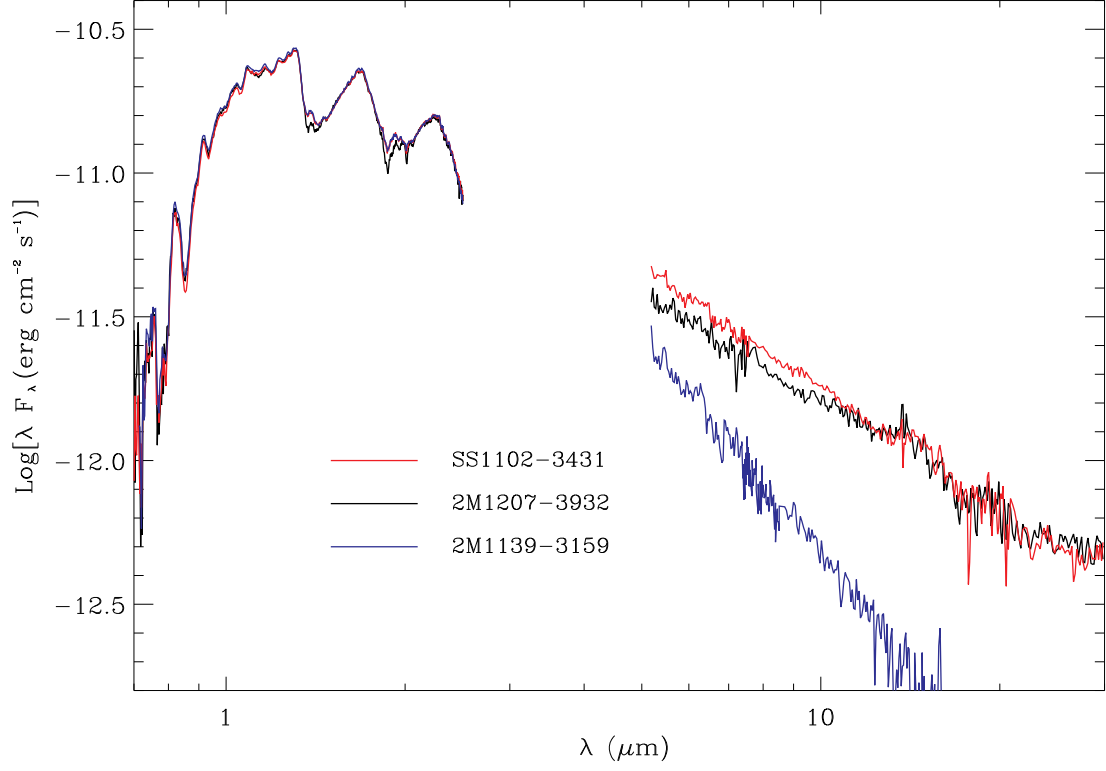


FIG. 2.— SEDs of the young brown dwarfs SS 1102-3431, 2M 1207-3932, and 2M 1139-3159 (*red, black, and blue lines*). Relative to 2M 1139-3159, SS 1102-3431 and 2M 1207-3932 exhibit excess emission at long wavelengths, indicating the presence of circumstellar disks. The difference between the SEDs of SS 1102-3431 and 2M 1207-3932 can be explained as a difference in the heights of their inner disk walls (Figs. 3 and 4). The SEDs of SS 1102-3431 and 2M 1139-3159 have been scaled to match that of 2M 1207-3932 at 1-2.5 μm .

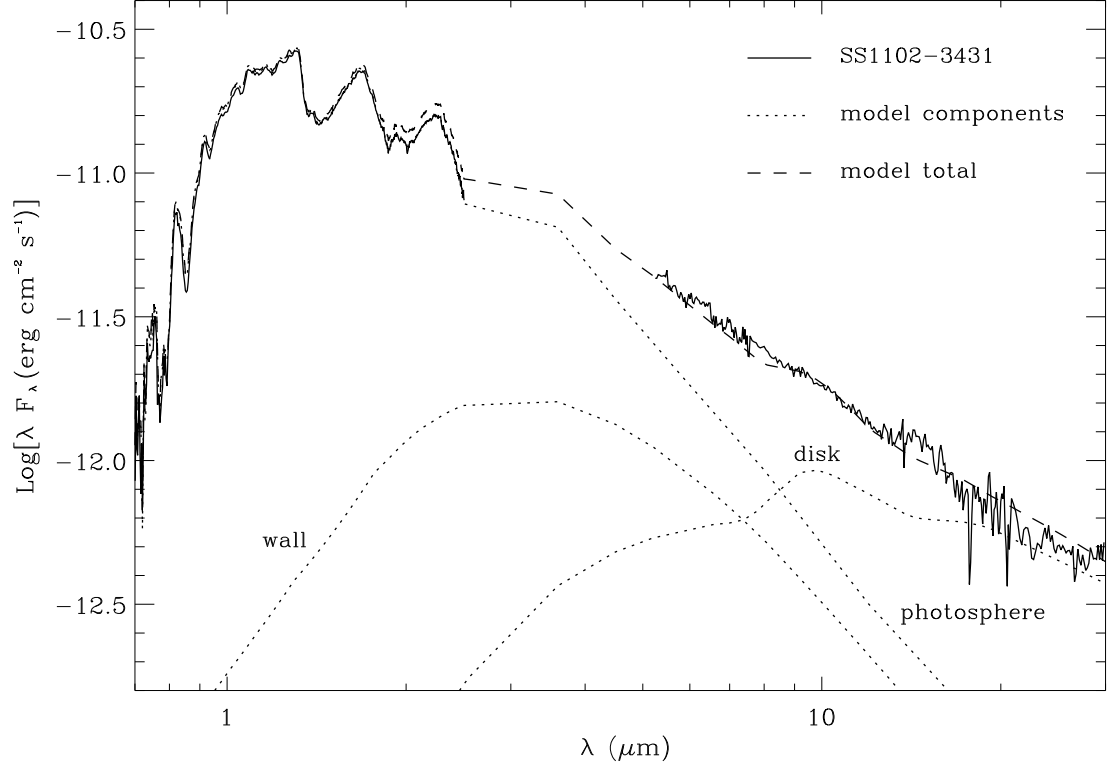


FIG. 3.— SED of SS 1102-3431 compared to a model for its circumstellar disk ($\alpha = 0.001$, $\epsilon = 0.001$, $i = 60^\circ$, $\dot{M} = 10^{-11} \text{ M}_\odot \text{ yr}^{-1}$, $z_{\text{wall}} = 2 H$, $R_{\text{in}} = 3.3 R_* = 0.83 \text{ AU}$, $R_{\text{out}} = 50 \text{ AU}$, $a_{\text{max}} = 5 \text{ } \mu\text{m}$ for small grains in upper disk). We adopted the SED of 2M 1139-3159 to represent the stellar photosphere of SS 1102-3431.

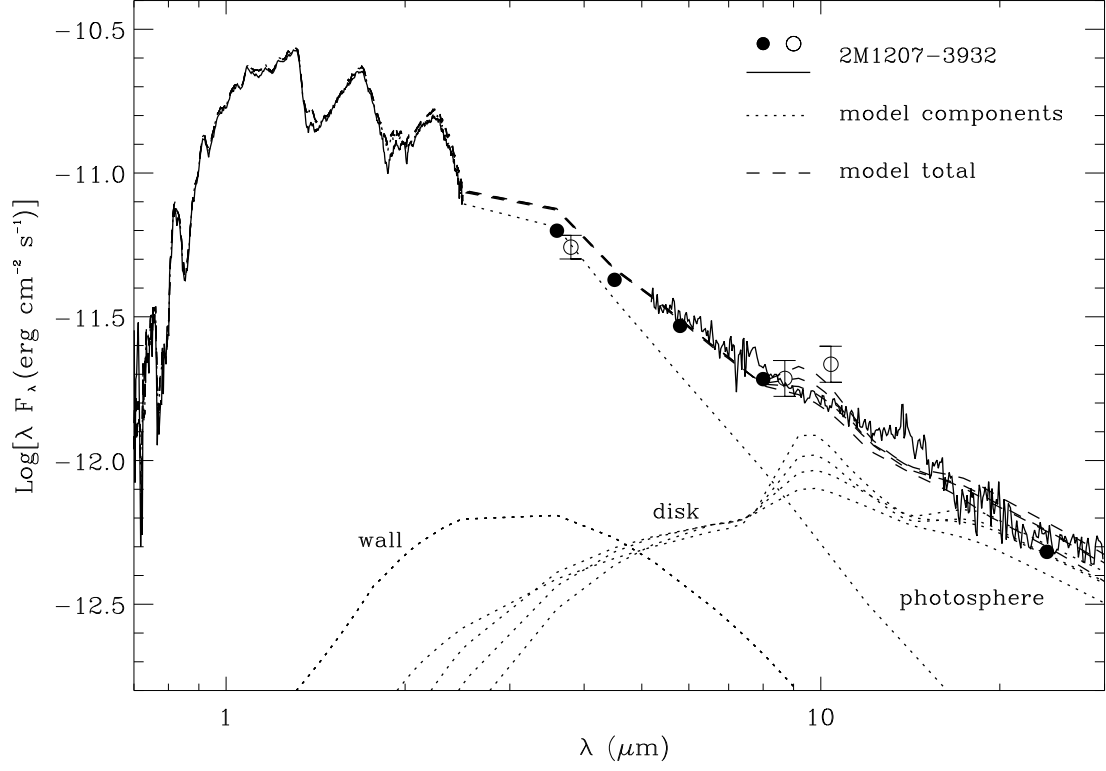


FIG. 4.— SED of 2M 1207-3932 compared to a model for its circumstellar disk. The model parameters are the same as for SS 1102-3431 in Figure 3 except that $z_{wall} = 1 H$ and four values of a_{max} are shown (0.25, 1, 5, and 100 μm). The predicted strength of the silicate emission near 10 μm is weaker for larger values of a_{max} . We adopted the SED of 2M 1139-3159 to represent the stellar photosphere of 2M 1207-3932. The photometric measurements are from Sterzik et al. (2004, *open circles*) and Riaz et al. (2006, *filled circles*).